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Technical, Economic and Environmental Comparison of Three Different Grid-Connected PV Tracking Systems Power Plant Under Kurdistan Region/Iraq Climate Condition

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Abstract: In this paper, a 1 MW grid-connected PV system was performed and simulated numerically in Zakho city, using hourly meteorological data for three systems; fixed, single-axis, and dual-axis tracking systems for solar module. The analysis of this study is based on technical, economic, and environmental feasibility. The analysis based on the actual 3 PV solar panels using different tracking systems which installed on the roof of the Engineering college of Zakho University. The evaluation findings suggest that PV technology is quite promising in this location, with annual yield factors of (1416 kWh/kW), (1694 kWh/kW), and (1902 kWh/kW) for the three systems, respectively. Furthermore, the proposed system's capacity factors are 16.2 percent, 19.3 percent, and 21.70 percent. The economic growth of a 1MW grid-connected photovoltaic (PV) system adjusted for meeting the daily peak load in Zakho is analyzed and compared based on the cost of electricity (COE), net present value (NPV), payback period (PBP), and the energy payback time (EPBT) for three systems in the present work. The COE for the three proposed systems, fixed, 1st axis, and dual axes solar tracking systems, was 0.0826 USD/kWh, 0.0489 USD/kWh, and 0.0441 USD/kWh, respectively, which indicated the tracking system is economically feasible. The findings indicate a favorable trend, implying that large-scale photovoltaics of dual-axis systems might be a feasible option for addressing future power needs.

Keywords: Grid-connected PV systems, Yield factor, Capacity factor, COE, NPV

Introduction

The utilization of renewable resources is the most effective way to achieve long-term solutions for energy sustainability, with various advantages such as being environmentally friendly and non-exhaustible (Salih et al., 2019). Solar energy is effective, inexpensive, and environmentally acceptable (Tsoutsos et al., 2005). In recent years, solar energy electricity has become very popular due to the low investment cost. A solar photovoltaic (PV) system converts the sun's irradiance into electrical power. The angle of incidence of sunlight determines the output power of solar energy. An optimum tilt angle for a fixed system may maximize output power (Chaturvedi et al., 2021; Fuke et al., n.d.; Xu et al., 2017). Due to the sun's site variation during the day, the angle of incidence changes, affecting the solar panel's performance. When the sun's rays are perpendicular to the solar panel's surface, maximum electricity is produced (Saeedi & Effatnejad, 2021). The geographical conditions vary between locations, so different studies are required. Two basic types of sun-tracking systems, the single-axis tracking system, and the dual-axis tracking system are used which depend on the sun movement. The researchers developed different sun tracking systems, single-axis tracking (Roong & Chong, 2016; Zhao et al., 2016) and dual-axis tracking (Fathabadi, 2016; Hong et al., 2016; Njoku, 2016; Parthipan et al., 2016). The tracking system with a single axis is a mechanism for tracking the sun around one side of the rotation pivot(Fathabadi, 2016; Gupta et al., 2015; Hong et al., 2016; Njoku, 2016; Parthipan et al., 2016). The primary disadvantage of a single tracking system is that it follows the sun during its movement and does not follow the annual movement of the sun. The efficiency of tracking systems is decreased significantly during cloudy days due to the rotating around just one axis(Jamroen et al., 2020). A solar dual-axis tracker is a process that uses two pivot nodes to rotate in two separate axes of the sun. The active tracking system determines the sun's location using sensing elements throughout the day. These sensors drive the engine or actuator to drive the system to the sun all day long. Active tracking systems arranged with various control types, such as microprocessor-based, electrical-optical sensor-based approaches, date and time, and auxiliary PV cells (Ferdaus et al., 2014; Leon et al., 2014; Vermaak, 2014). Many studies are presented in the literature that deal with the tracking system. Fahad et al. (Fahad et al., 2019) demonstrated a performance comparison study of total incident solar energy on photovoltaic panels of the same size for three distinct tracking systems (fixed, single, and dual) during twelve months, with and without cloud cover in Bangladesh. The results reveal that there is no statistically significant variation in energy yield between single-axis and dual-axis trackers. F. Alfirjani (Abdulhamid & Alfirjani, 2021) designed three different tracking systems (fixed, single-axis, dual-axis) with identical solar panels of the same power and compared according to their efficiencies, the performance of three alternative systems is relatively near to each other across all parameters, however, it differs due to the locations. The findings display that the dual-axis solar tracker was 5.43 percent more efficient than a single-axis solar tracking system and 24.04 percent more efficient than a stationary solar panel. Tangi (Tangi, 2017) demonstrate that the dual-axis tracker is superior to any existing solar tracker, utilizing a microcontroller and motor drivers. The dual-axis sunflower tracker was cost-effective and fairly efficient and has the potential to make a significant difference in India's future of sustainable solar energy. Hoque et al. (Hoque et al., n.d.)presented two solar energy collection technologies, dual and single axes solar trackers are designed, fabricated, and tested. The power output and efficiency are increased by 69.85% for dual-axis solar tracker and 44.74% for single-axis solar tracker.

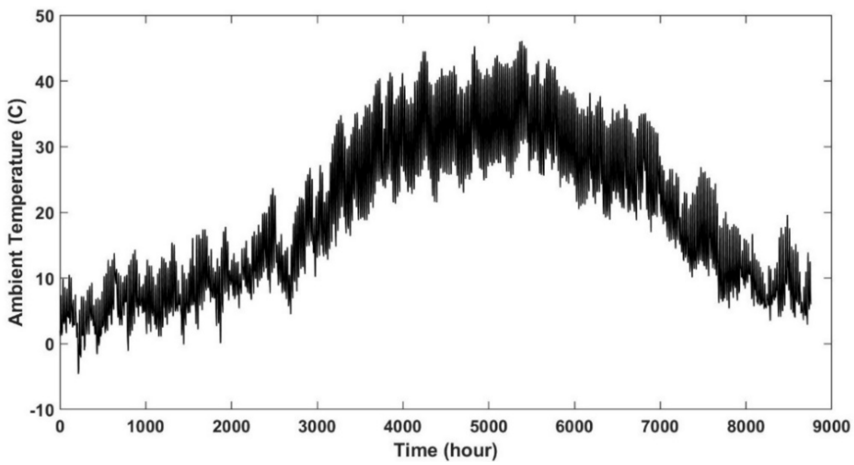
The tracking system significantly improves large-scale solar system’s technical and economic performance in many solar applications. Tracking angles depend on the latitude of the place and the climate. Fuke et al. (Fuke et al., n.d.)investigated the technical performance and economic assessment of fixed, 1-axis, and 2-axis tracking orientations under geographical and climatic circumstances in Mumbai. During the summer, more power is obtained using a 1-axis tracking system compared to a fixed system. Furthermore, a 2-axis tracking system produces just 3-4% more electricity; as can be observed, there is no significant increase in producing power when using a 2-axis tracking system compared to a 1-axis system.

Several studies conducted in middle east countries deal with the technical performance and economic feasibility of PV solar energy power plants (Kazem et al., 2017; Allouhi et al., 2016; Audenaert et al., 2010; Drury et al., 2011; Vermaak, 2014) . Most of the studies which dealt with solar energy in Iraq which investigate the energy performance of the solar energy system (Ahmed & Ali, 2019; Ali & Jameel, (2011); Ali, 2020; Alomar & Ali, 2021; Alyousifi & Ali, 2019; Hussain & Mahdi, 2018; Bamisile et al., 2019; Chaichan & Kazem, 2018; Kazem & Chaichan, 2012; Khaled & Ali, 2020; Oudah, 2020; Salah, 2021; Zubeer & Ali, 2021, 2022). The studies that dealt with the technical and economic feasibility in Iraq is rare. Oudah and Salah (Salah, 2021) investigated theoretically the energy and economic performance of a proposed grid-connected PV Power Plant with a capacity 4 MW to produce the energy at AL- Mahmudiyah region. The results indicated the construction of the grid-connected PV Power Plant for electricity production is feasible due to its cost-effective. Also, the energy and economic feasibility studies for PV power plant using tracking systems are very little in Iraq. Hussein and Mahdi (Kazem et al., 2017)performed an environmental and economic feasibility study for a 10 MW sun-tracking PV power plant in the western region of Iraq. The total electrical power achieved using a dual-axis tracking system throughout the lifetime

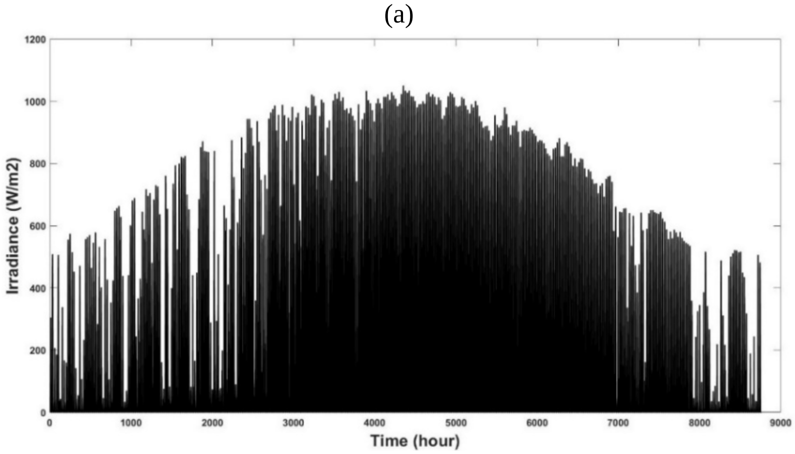
In recent years, the shortage in electrical production and pollution problems of the power plants that uses fossil fuels are great challenges in Iraq. The improvement of the economic and technical performance of fixed PV solar panels has been the main priority of researchers because they need a huge installation area. The employment of the tracking system for PV solar energy power plant is one of the best methods to increase the energy production. From the literature review, the studies which deal with the performance of solar systems using tracking systems is not considered and there are rare theoretical and experimental studies in Iraq which deal with this subject. Therefore, the present study aims to make a technical, economic, and environmental feasibility study to compare three different solar tracking systems fixed with constant tilt angle, single-axis, and dual-axis, to evaluate the impact of the factors on a grid-connected PV power plant in Zakho city using actual meteorological data. Simulation models are applied to design the planned PV power plant. The proposed grid-connected PV power plant has a 1 MWp system capacity. The system includes a grid-connected inverter, which is utilized to produce power from the grid. The PV power plant is compared with Iraq's available fossil fuel plants. This research is becoming earlier research done for northern Iraq, which compared three distinct solar systems and relied on real meteorological data to establish the feasibility of the intended power plant.

Zakho city Weather and Location Conditions

This section explains the yearly weather conditions in Zakho, Iraq. The actual data provided upon an hourly rate for 2019 includes the radiation from the sun intensity, temperature, and wind speed (*NREL Solar Spectra*, 2020), as seen in fig. 1. The ambient temperature in Zakho city varies from –4.9 to 46.7 °C, as illustrated in fig. 1(a), and the temperature reaches its highest during the summer. The radiation from the sun intensity, as illustrated in fig. 1(b) is an important factor in determining where to build PV systems. North Iraq as a whole has spectacular total solar insolation values that have reached 1050 W/m^2. Fig 1(c) depicts the city's local wind speed around an hourly rate over a year. The wind speed in the area fluctuates from 0.2 to 8.8 meters per second. Because the average wind speed in Zakho/Iraq is far less about 2 m/s, the influence of wind speed on PV systems is not as substantial as solar irradiation and ambient temperature.



(a)



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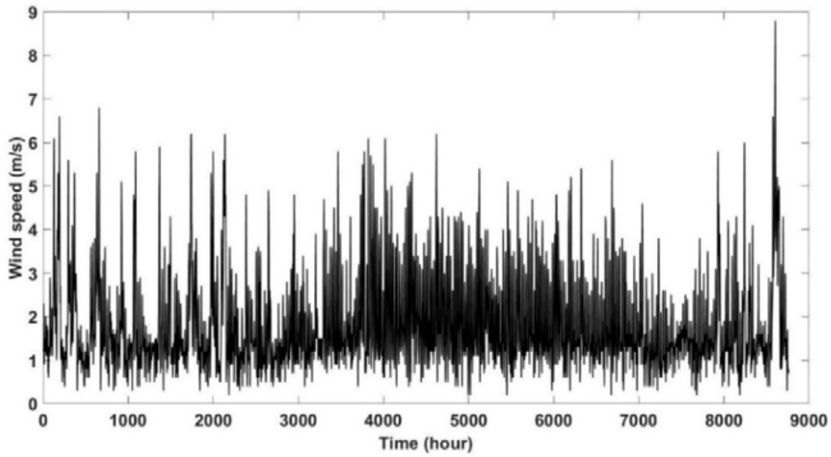


(c)

Figure 1: (a) Ambient temperature in °C, (b) Hourly solar insolation in W/m^2, (c) Wind speed in m/s for an entire year (2019).

Determining of Plant Output

Zakho is a bordering state in the northwestern part of Duhok Governorate, located at 37.15° north and 42.67° east. The city has around 1375 sq. km, which allows for installing PV panels (Wikipedia, 2021). The city of Zakho is located in a hilly environment, which is ideal for a PV plant because there is less concern about dust impacts. Considering the geographical situation, the PV capacity is on a stable foundation. However, the plant's design will produce excellent technological and economic outcomes.

Modeling of Grid-Connected PV Seystem

A photovoltaic solar panel and an inverter are the components of a grid-connected PV system. In Zakho, a 1 MWp PV system was recently simulated. As a result, this study assumed that a 1 MWp PV is developed in the Zakho area for research and development purposes. The same system is used for three types of power plants; fixed, single-axis, and dual–axes tracking solar systems. The present feasibility study depends on the actual solar panel installed in the Zakho city as displayed for the single and dual-axis case as shown in fig. (2). The specifications of the simulated PV system are shown in Table 1.

Table 1. Modelled PV system specification.

PV array (Multi-c-Si)	Canadian Solar Inc. CS6A-150PE
PV module rated power **(6720 modules)**	150W
Module Area	1.3 m^2
Maximum Voltage	23.1V
Maximum Current	6.5A
Open circuit voltage Voc	28.8V
Short circuit current Isc	7.1A
Solar cells Efficiency	12%
Current temperature coefficient	0.006A/C
Voltage temperature coefficient	-0.107 V/C
Inverter	SunPower: SPR-15000m-3[480V]
Rated Power (4 inverters)	15kW

A sequence of hourly data of total solar radiation and ambient temperature provided by the National Renewable Energy Laboratory (NREL, 2020) is utilized to simulate the anticipated PV system. Furthermore, applying a PV array mathematical model, these data are utilized to compute the DC power provided by the PV panel. Additionally, the Ac output is computed by taking the inverter efficiency into account (inverter mathematical model). Following that, the proposed system is evaluated by using the evaluation criteria that have been established.

Figure 2: Single and dual axis PV-panel systems of Zakho City

PV Array Model

The PV array's output power is determined by the obtainable solar radiation (G) and the ambient temperature (T). A PV array's output power rises proportionally as solar radiation rises and falls as ambient temperature rises(Wang et al., 2020). As a result, the instantaneous output of a PV array (Patel, 1999) may be calculated as,

$$P_{mp} = G\eta_m A_m (\frac{\gamma_{mp,ref}}{100})(T_c - 25) \quad (1)$$

Where G is the solar insolation, η_mm is the efficiency of the module, $\gamma_{mp,ref}$ is the temperature coefficient of the PV panel power and T_c is the temperature of the cell, and it is given by,

$$T_c = T_a + \frac{G}{800}(T_{noct,adj} - 20)(1 - \frac{\eta_{ref}}{\tau\alpha})\frac{9.5}{5.7+3.8v_{w,adj}} \quad (2)$$

where NOCT is the nominal operating cell temperature, which can be measured practically at 800 W/m^2, 1.5 m/s wind speed and 20°C ambient temperature. However, considering Eq. (1), the hourly ambient temperature and solar radiation records for the chosen location have been gathered. The PV reference efficiency is obtained from:

$$\eta_{ref} = \frac{I_{mp}V_{mp}}{1000A_m} \quad (3)$$

Where $I_{mp}$is the module maximum power current rating, A, V_{mp} is the module maximum power voltage rating (V), and Am is the area of the module, m^2.

Inverter Model

The efficiency of an inverter (Khatib et al., 2012)is calculated by,

$$\eta(t) = \frac{P_{in}(t) - P_{Loss}(t)}{P_{in}(t)} \quad (4)$$

Where P_{Loss} (t) and P_{in} (t), are the power loss and instantaneous input power during the conversion. The PV system's input power equals the PV module's output power, ignoring wiring losses. Calculating to be difficult, the PLoss is not constant and is affected by various factors. As a result, an alternate model for inverter efficiency must be established to determine the output power of the inverter. It is possible to acquire the input power (DC) as follows:

$$P_{dc,0} = \frac{P_{ac,0}}{\eta_{inv,0}} \quad (5)$$

Fig. 3 depicts an efficiency curve derived from the datasheet for a commercial inverter. The graph depicts the inverter's efficiency (in percentage) in input and rated power. As a result, samples of the inverter's efficiency curve (illustrated in Fig. 3) should be collected for curve fitting.

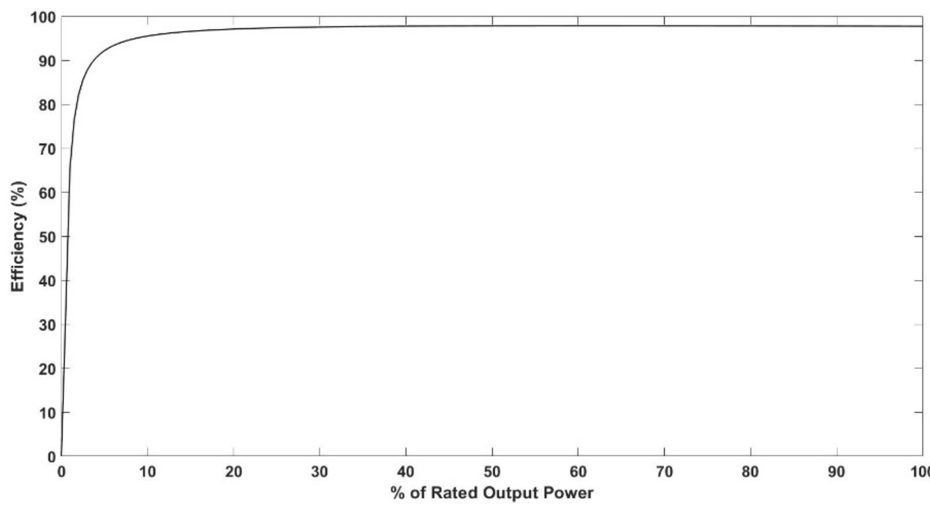


Figure 3: Typical efficiency curve for an inverter.

Criteria of PV grid-connected prodeucts for evaluation

Technical parameters

Technical and economic evaluation criteria can be utilized to determine the viability of a grid-connected PV system. Technical criteria, such as yield factor, capacity factor, and performance ratio, are considered in this research. The economic evaluation criterion and calculation methods are described in-depth in the following paragraphs. A yield factor YF is also defined as annually, monthly or daily net Electrical energy production of the system divided by the maximum output power of the PV array that is mounted under standard test conditions STC, and it is also provided by (Kymakis et al., 2009),

$$YF = \frac{E_{PV}(kWh/year)}{PV_{Wp}(kWp)} \quad (6)$$

where E_{PV} is the system's energy yield, and PV_{WP} is the PV array's nominal power (P_{STC}). Under certain weather parameters, the above factor affects the production of a PV system. The capacity factor, on the other side, is defined as the ratio of actual yearly energy production to the quantity of energy a solar PV array would produce if it is maintained at full rated power for a year (Kymakis et al., 2009),

$$CF = \frac{Y_F}{8760} = \frac{E_{PV\,annual}}{P_R * 8760} \quad (7)$$

This factor evaluates the usage of the PV array. The performance ratio P_R is the ratio of the actual energy output of a PV system to the theoretical standard test condition output for a given reporting period,

$$P_R = YF \frac{G_{STC}}{\sum G_t} \tag{8}$$

where G_{STC} is the amount of irradiance at standard test conditions, STC and $\sum G_t$ Are the accumulative irradiance on the plane of the PV array within a certain period (annual, monthly, or daily).

Economic Parameters

This factor rates the PV array's use. Life cycle cost (LCC), payback time, and cost factors can be utilized for the economic analysis. The total cost is defined by,

$$\text{LCC} = \text{C}_{\text{capital}} + \sum \text{C}_{\text{O\&M}} + \sum \text{C}_{\text{replacement}} - \text{C}_{\text{salvage}} \tag{9}$$

A project's capital cost ($C_{capital}$) must include the initial capital cost for instruments, system design, and operation. This cost is often viewed as a single fee paid during the first year of its project. Cost of maintenance ($C_{O\&M}$) is the total of all annual operation and maintenance expenditures. Operators' income, inspections, security, and local taxes are all examples of O&M costs. The replacement cost ($C_{replacement}$) is the total of all equipment repairs during the duration of the system. Typically, these expenditures happen in defined years, and the entire cost is incurred throughout those years. Eventually, a value of system salvage ($C_{salvage}$) is its net valuation in the final year of its life cycle. For mechanical devices that may be evacuated, it is usual practice to give a salvage rate of 20% of the initial cost. This rate can be adjusted based on other variables such as obsolescence and equipment conditions (Hong et al., 2016). Furthermore, the cost analysis is based on the actual solar panels placed in Zakho city. Note that installing grid PV systems comes with an additional cost for single and dual axes tracking systems which are often replaced after a certain period. Thus these higher costs are taken into consideration. After determining the LCC, the unit price of the energy may be determined as follows:

$$\text{CoE}=\frac{\text{LCC}}{\sum_1^n \text{E}_{\text{PV}}} \tag{11}$$

This model computes the power provided by an array and other system losses such as temperature inverter waste, wire damage, etc. Following that, the rating factors employed in this study are derived using Eqs. (5), (6), (7), and (9). The net present value (NPV) is critical in analyzing its economic viability since it indicates the net profit produced. A positive value of NPV shows that investing in the project would be productive. The net present value (NPV) is a difference between the current value of cash flows throughout the project's life and the original capital cost. The following formula can be used to calculate (Drury et al., 2011):

$$\text{NPV} = \sum_{\text{t}=0}^{\text{N}} \frac{\text{Revenue}}{(1+\text{i})^{\text{t}}} - \text{initial cost} \tag{12}$$

where N denotes the number of years for the economic study, typically the project lifecycle, t represents the year, and I denotes the interest rate. The yearly income may be determined by multiplying the PV system's energy output by the energy price. The following equations can be used to compute annual revenue (Audenaert et al., 2010):

$$\text{Revenue (year} = \text{i)} = \text{ Energy produced} \tag{13}$$

The payback period (PBP) calculates the time it takes for the system to return its initial investment. A shorter PBP time is preferable since the project returns its original cost in a shorter time. PBP is the amount of time necessary to reduce NPV to zero. To compute PBP, first determine if the project's overall NPV during its lifecycle is negative. If that is, it shows that the project is not possible. If the Net present value is positive, the parameter N in eq. (11) is decremented in 0.25-year stages, and the NPV is computed for every step till the NPV is equal to 0, at which point N equals PBP.

Environmental Impact

Various greenhouse gases, particularly CO2, contribute to environmental contamination. CO2 emissions are the major source of the potential issue of global warming. CO2 is regarded as pollution when combined with power plants that use fossil fuels to generate electricity (Allouhi et al., 2016). The photovoltaic system is among the most environmentally friendly energy generation methods. In the current study, the environmental effect of each deployed technology is determined only by the embedded energy and CO2 equivalent emissions. As a result, the current paper explores the possibility of lowering CO2 emissions by installing such PV systems.

Validation of the Present Work

The cell temperature of the present work compares with theose of the available experimental results by Zubeer and Ali (Oudah, 2022)for a day of 24th September 2019 for Duhok city (it closer to Zakho city), as shown in figure (4). The agreement between two studies is good with a maximum error value of about 8% due to some difference in the climatic conditions.

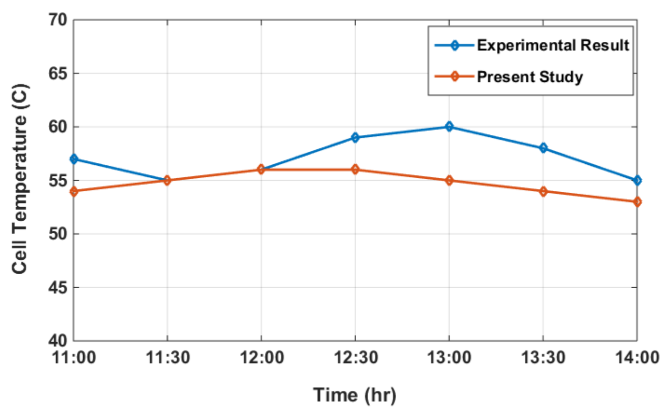
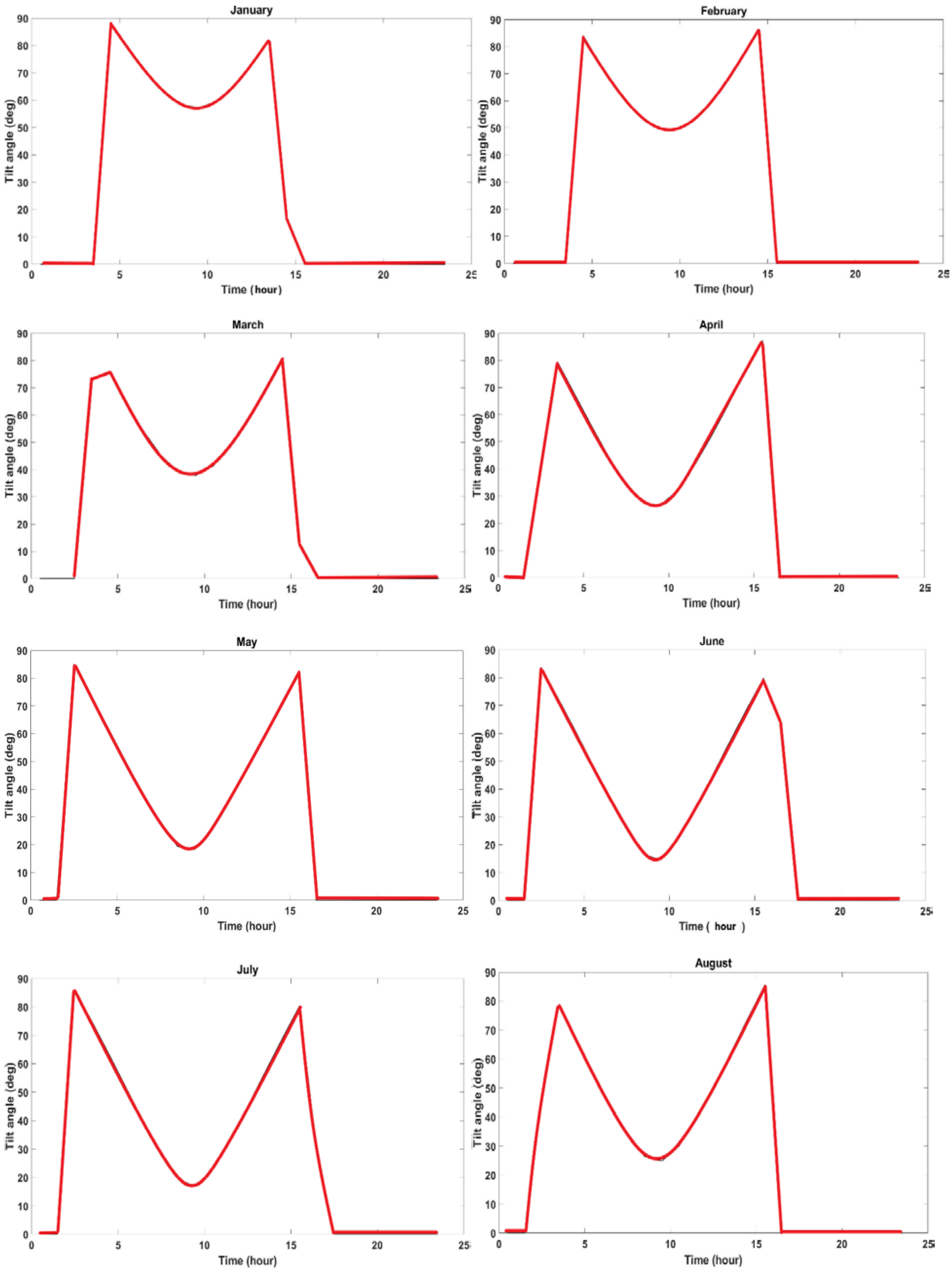


Figure 4:The cell temperature of the present work compared with another experimental work

Results and Discussions

According to the simulation findings, the system was tested for a year. Furthermore, the annual energy produced for three systems (fixed, single-axis, and dual-axis) for 1 MW power plants is around 1428466 kWh, 1709710 kWh, and 1919613 kWh. These results indicate an increase in the produced energy with 34% and 19.6% for power plants with dual and single axes tracking systems compared to the fixed system. The annual yielded energy produced by the PV power plant for Zakho city in the first year is approximately 1,416 kWh/kW, 1,694 kWh/kW, and 1,902 kWh/kW for three systems, respectively, which mean that the employment of the single-axis and dual-axes tracking systems for PV power plant increases the produced energy by 19.6% and 26% as compared with those of fixed panels. In contrast, the performance factors of the planned power plant are approximately 0.71, 0.71, and 0.69, respectively. The annual capacity factor for fixed, single-axis and dual-axes tracking systems are 16.2 percent, 19.3 percent, and 21.70 percent. The energy findings indicate that the employment of the tracking systems have a positive influence on the energy production. As illustrated in Fig. (5-6), the optimal tilt angles of the PV power plant/month are achieved. The monthly fluctuation in the ideal tilt angles is caused by the change in the altitude between the sun and earth, which changes the optimal values of the PV tilt angle regularly. A varied tilt angle delivers more output energy and peak power for the planned power plant every month. The average optimum tilt angle for each month is displayed in figure 6. To enhance the accuracy in determining the larger output energy and peak power that will be generated, a unique tilt angle equivalent to the recurring month tilt angles is selected. The optimum tilt angle is approximately equal to the latitude of Zakho city since it is the best tilt angle for five months. Therefore, the optimum tilt angle is selected for the fixed solar panel. Also, the simulations involve the cell temperature distribution for the PV panel, figure 7, which have an effect on the PV panel efficiency. The panel temperature increase with the increase of the ambient temperature and solar radiation intensity.


January
February
March
April
May
June
July
August
Tilt angle (deg)
Time (hour)

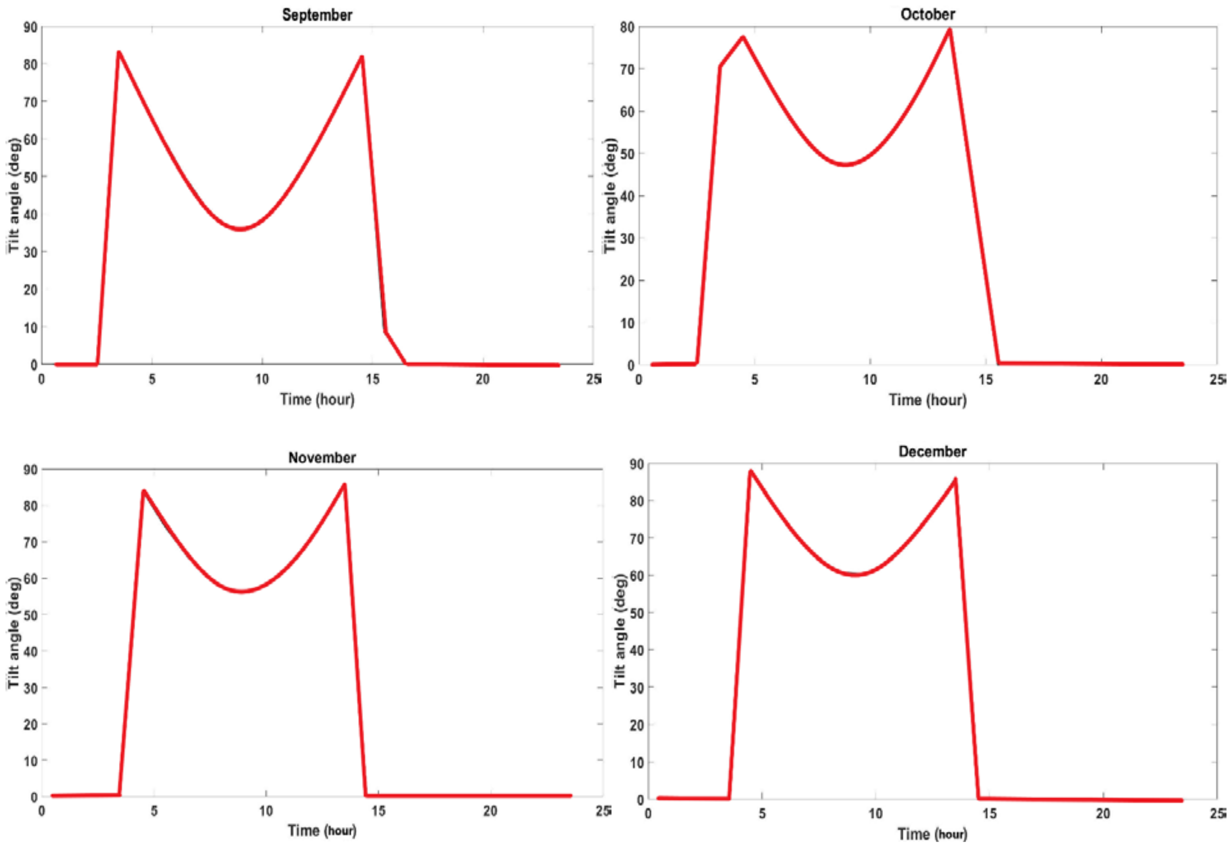


Figure 5: Optimum tilt angle for all months versus time

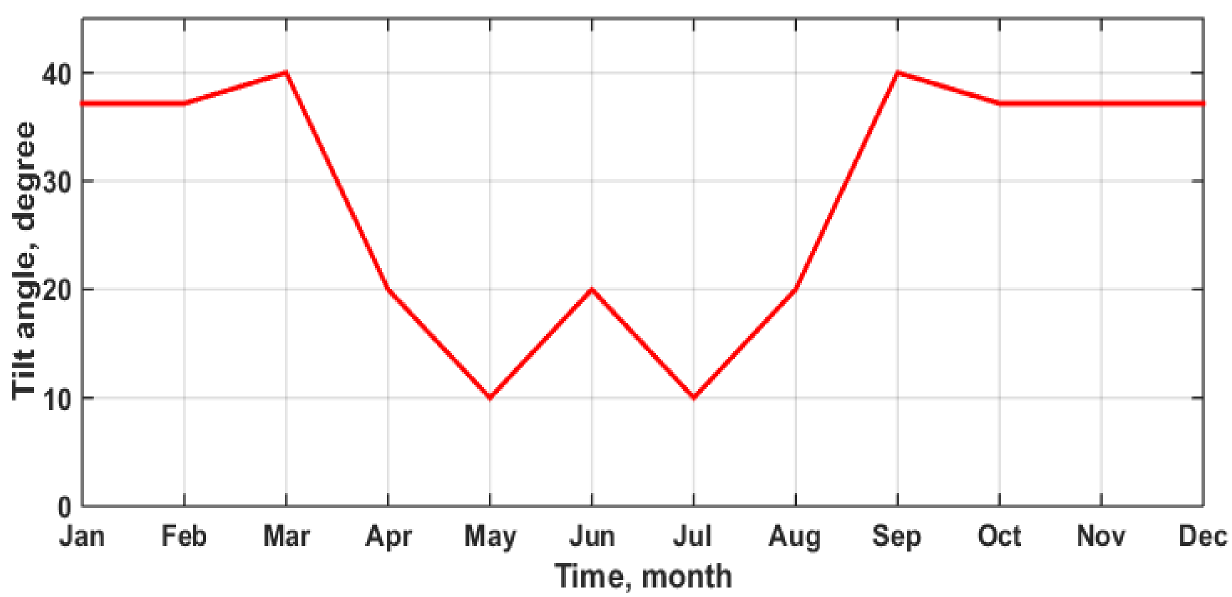


Figure 6: Monthly optimum tilt angle

The comparisons of generated energy, capacity factor, and yield factor for different 3 tracking systems are illustrated in figures 8 – 10. As seen in fig. 8, the energy production ranges for fixed, single-axis, and dual-axis systems are (62 – 150 MWh), (50 – 220 MWh), and (80 – 230 MWh), respectively with peak energy production for three systems is around 150 MWh, 220 MWh, and 230 MWh, respectively, showing an enhancement percentage with 31% and 34.7% for single and dual axis as compared with fixed panel system. Maximum enhancement for three systems are obtained in May and July months while lowest energy output for these systems indicated in January and December months. The capacity factor of a suggested plant is depicted in figure 9, for three systems which ranged between 20-32 %, 22 – 48 %, and 23 – 50 %, respectively. This factor fluctuates between the lowest values in the winter and maximum values in the summer. Figure 10 display the the yield factor distribution for 3 tracking systems during 12 months' data. The highest results are reached for intended systems within the summer months of May – September due to the high ambient temperature and solar insolation. For some winter months, the yield factor for the PV power plant of 1-axis is more than those of 2-axis.

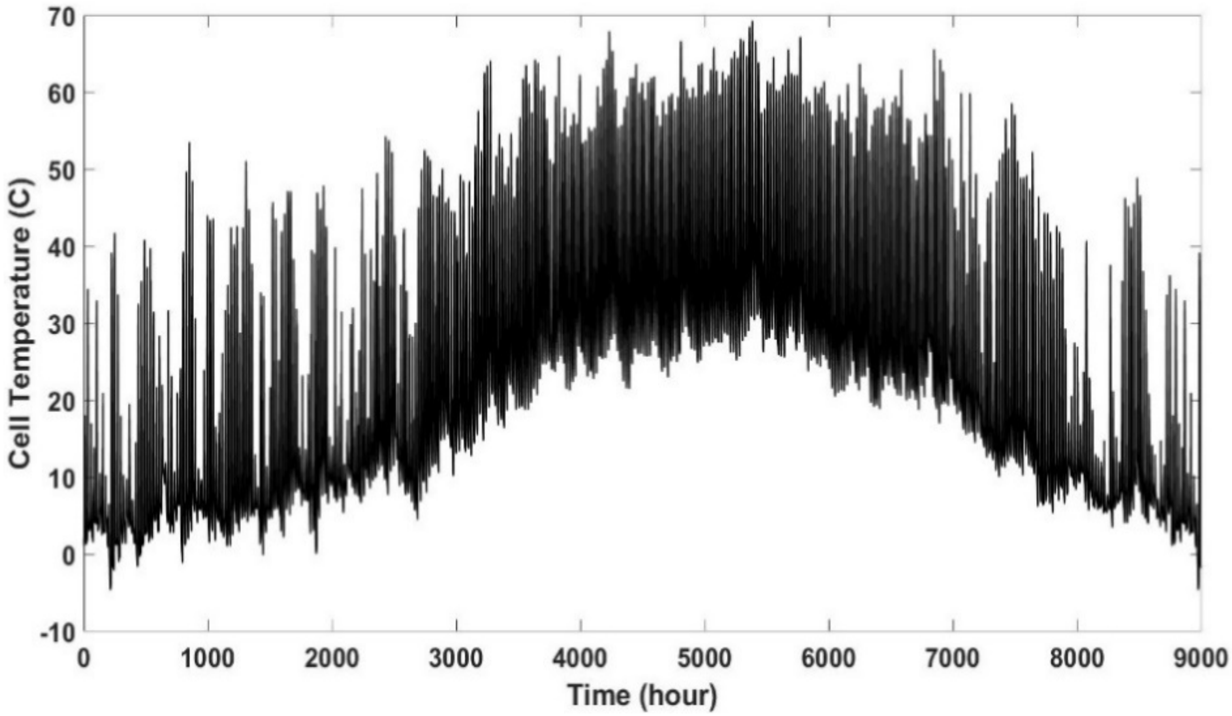


Figure 7: Hourly cell temperature in ℃

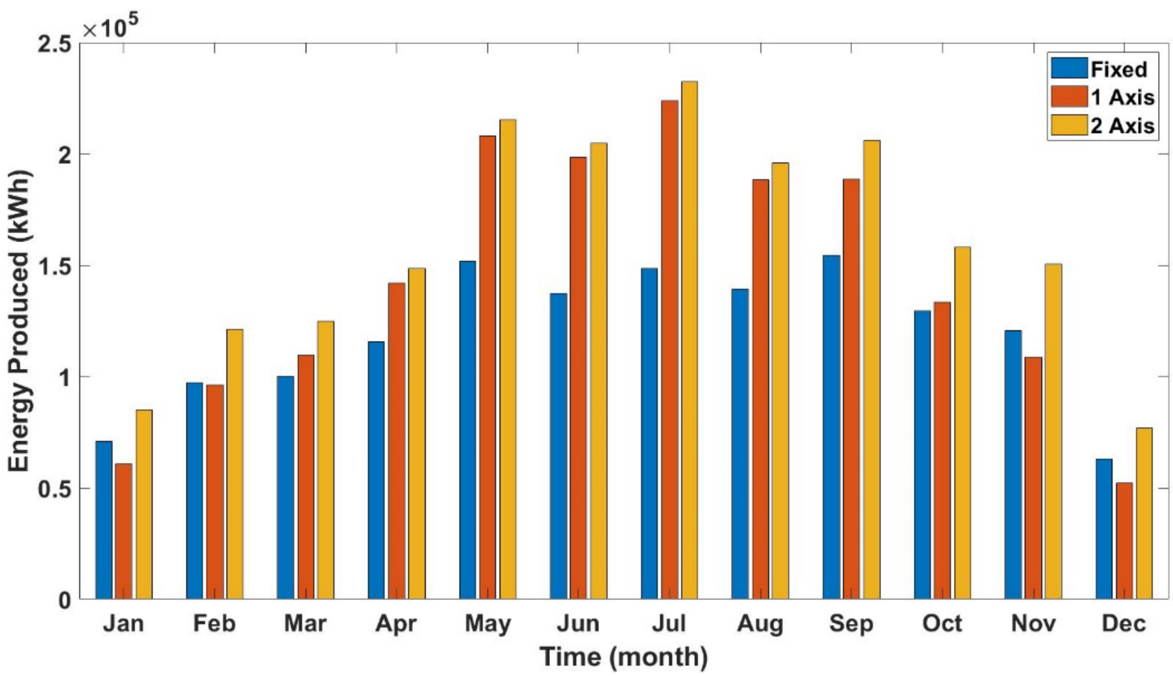


Figure 8: Monthly energy production, kWh

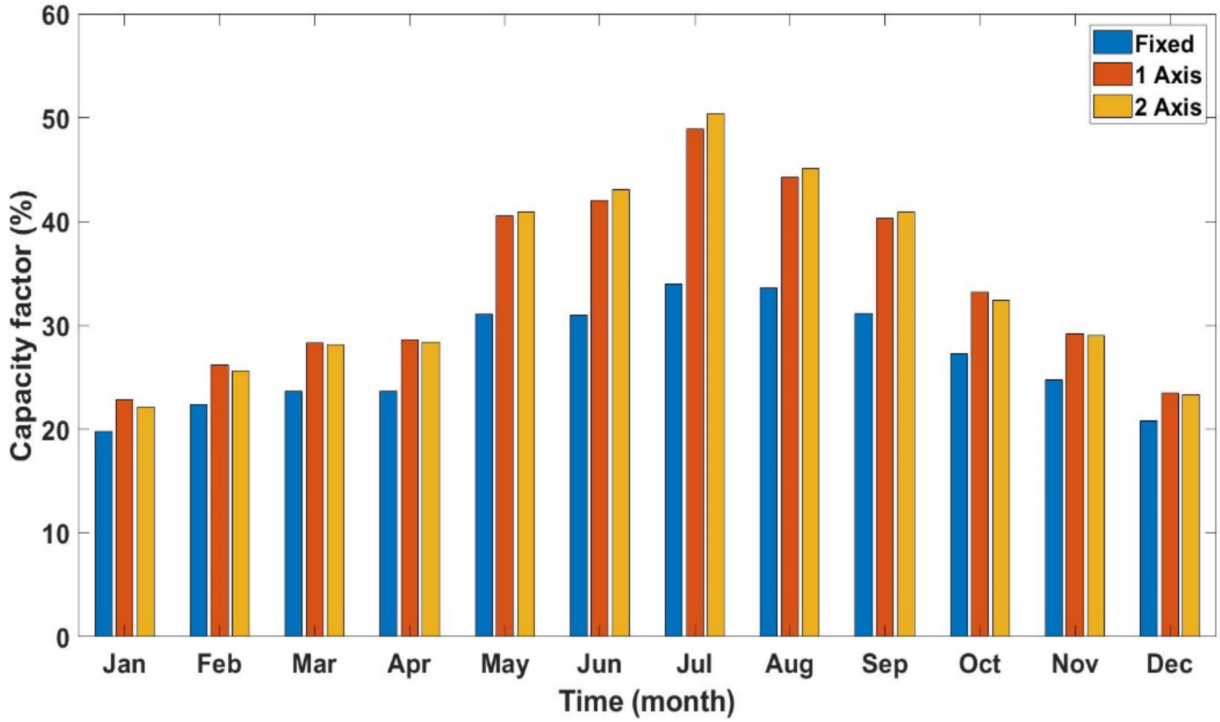


Figure 9: Monthly capacity factor

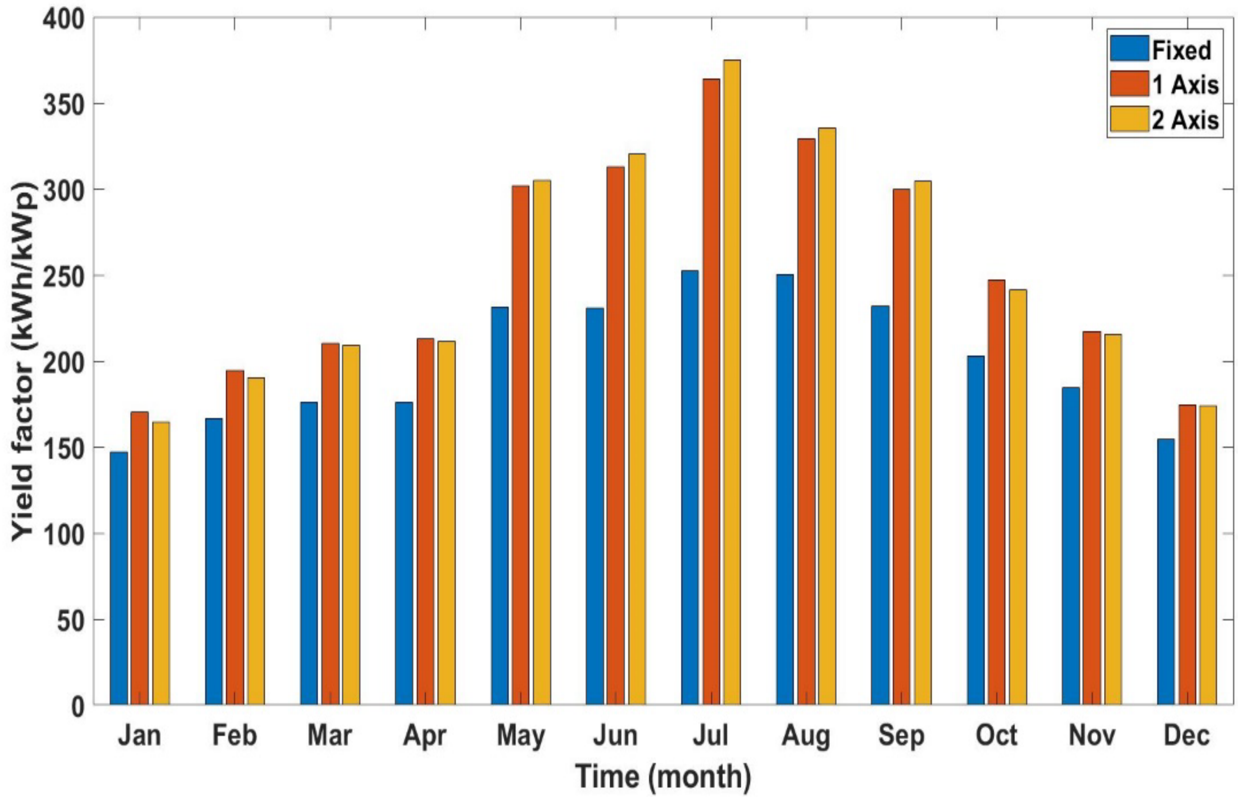


Figure 10: Monthly yield factor, kWh/kWp

Three PV solar panels are installed on the roof of the engineering college with the solar panel specification that displays in Table 1. The cost of the fixed PV solar panel includes the support structure and other accessories, while the single axis and dual axes tracking systems include the cost of the fixed panel plus additional cost due to the tracking systems. Therefore, the economic analysis depends on the actual prices in local Iraq markets.

The results of the economic analysis display in figure 11 and table 2. Figure 11 demonstrates that the PV power plant income increases and the cost of the intended power plant will be recovered after 9 years for a fixed system and about 15 years for the other two systems (single-axis and dual-axis). Table 2 displat briefly the comparison of the technical and economic results for three tracking systems of the PV power plants. The findings display that the CoE of a PV power plant for fixed, single, and dual-axis systems is 0.083, 0.049, and 0.044 USD/kWh, respectively, which displays that the tracking systems increase the energy production despite of the expensive installation costs. The NPV for 1 and 2 axes tracking systems is low, therefore, the payback period is long as compared with fixed panel. Due to government backing, the cost of energy in Iraq is lower than in other nations due to the government's minimal taxation (Kazem et al., 2017).

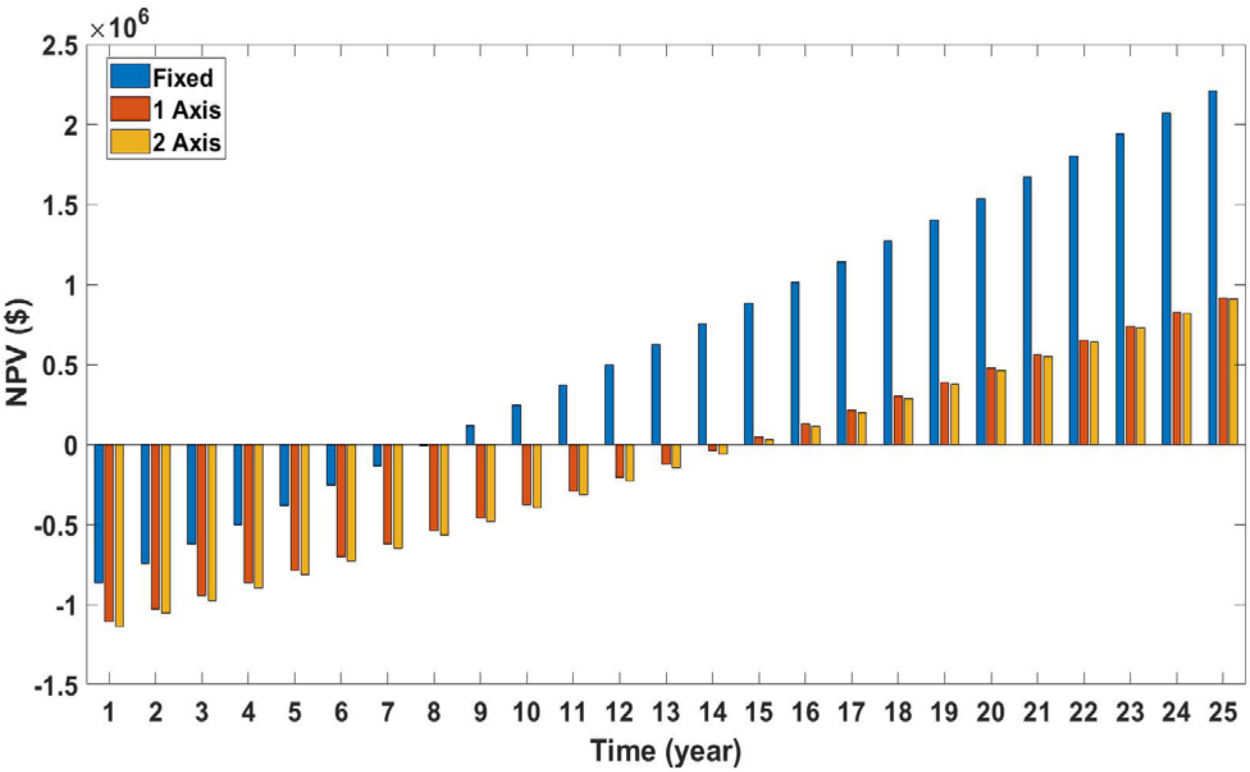


Figure 11: Net Present Value for PV power plant (1 MW) during its lifetime

The CO2 emission analysis displays that the CO2 emission is very low for PV power plant as compared with those of other power plants that employ fossil fuels, table 3. The fossil fuels in the table are selected because these fuels are used in Zakho city for central power plants and local generators. The CO2 emission reduces when fixed PV power plants are used instead of Natural gas and gasoline with the values of 472.8 and 3292.6 tCO2, respectively; 565.9 and 3940.8 tCO2 for single-axis, and 635.4 and 4424.7 tCO2 for Dual-axis. Table 4. Displays the generated energy, installation cost, fuel cost, O&M cost, and social cost for different power plants. The produced energy for a 1 MW power plant using gas turbine and steam turbine power plants are about four times of PV energy. Fossil fuels are very expensive compared with PV power plant costs. The running cost of PV power plants is very low, and the fuel is not required, while other power plants require fuels and expensive maintenance. Therefore, the running cost of the power plant is considered expensive. The CO2 emission affects the community with a social cost in which each tCO2 cost equals 50 USD (Rafaty et al., 2020). The employment of the tracking systems for PV power plant have not influence on the CO2 emission.

Table 2: Technical and economic parameters results

Item	Unit Price			Value		
Type of PV System	Fixed	Single-Axis	Dual-Axis	Fixed	Single-Axis	Dual-Axis
PV array 6720X150Wp	0.38USD/Wp	0.38USD/Wp	0.38USD/Wp	383,423.03 USD	383,423.03 USD	383,423.03 USD
The support structure, circuit breakers, transformers, and cables				201,801.59 USD	302,702.41 USD	332,972.62 USD
Inverter (15kW) × 220	0.06 USD/Wp	0.06 USD/Wp	0.06 USD/Wp	60,540.48 USD	60,540.48 USD	60,540.48 USD
Installation and commissioning				110,990.88 USD	161,441.28 USD	161,441.31 USD
Total				756,756.00 USD	908,107.19 USD	938,377.44 USD
Salvage Value				19,372.95 USD	27,243.22 USD	28,151.32 USD
Operation and maintenance				13 USD/KW-yr.	13 USD/KW-yr.	13 USD/KW-yr.
The total area of modules				8736m^2	8736m^2	8736m^2
Land area				87360 m^2	17470 m^2	17470 m^2
Energy Yielded				1,416 kWh/kW	1,694 kWh/kW	1,902 kWh/kW
System Lifetime				25 Years	25 Years	25 Years
Annual energy produced				1,428,466 kWh	1,709,710 kWh	1,919,613 kWh
Capacity factor				16.2%	19.3%	21.70%
Performance ratio				0.71	0.71	0.69
COE				8.26 cents/kWh	4.89 cents/kWh	4.41 cents/kWh
NPV				120,334 USD	22,354 USD	22,860 USD
IRR				11 %	11 %	11 %
PPA price				9.15 cents/kWh	5.03 cents/kWh	4.53 cents/kWh
Simple Payback period				9 years	15 years	15 years

Table 2. CO_2 emission factors, CO_2 emission results, and annual energy for some fuels and materials

	CO2 Emission Factor, tCO2/MWh		Annual Energy MWh	CO2Emission, tCO2	
	Natural gas	Gasoline		Natural gas	Gasoline
Fixed			1428.466	472.8	3292.6
Single-Axis	0.331	2.305	1709.71	565.9	3940.8
Dual-Axis			1919.613	635.4	4424.7

Table 3. Comparative between PV and fossil fuel power plants

Costs	Power Source		
	PV	Gas turbine	Steam turbine
Initial cost, USD	1800000	2,200,000	10,063,000
O&M cost, USD/ year	18000	133,000	396,500
Social cost, USD/ year	0	44,350	100,850
Fuel cost, USD/ year	0	235,725	279,000
Total cost, USD	1818000	2,613,075	10,839,350

Conclusion

In the present work, 1 MW_p PV power plants using fixed, single, and dual solar tracking systems for PV solar panel in Zakho city are evaluated and simulated depending on the actual metrological data and solar panels installed in Zakho city. The study's primary conclusions are explained in the following sections:

- The findings demonstrate that the power plant yield factor per year for the three recommended systems is 1,416 kWh/kW, 1,694 kWh/kW, and 1,902 kWh/kW, respectively.
- When compared to fixed panels, the use of single-axis and dual-axis tracking systems for PV power plants improves the produced energy by 19.6 percent and 26 percent, respectively. In comparison, the proposed power plant's performance factors are roughly 0.71, 0.71, and 0.69, respectively.
- The annual capacity factors for these systems are 16.2 %, 19.3 %, and 21.7 %, respectively.
- The PV system's potential as an energy-positive and sustainable source and a financially attractive investment was assessed using COE, NPV, PBP, and EPBT.
- The COE for the three anticipated systems was calculated to be 0.0826 USD/kWh, 0.0489 USD/kWh, and 0.0441 USD/kWh, which is less than the current actual cost of a kWh of production in Zakho city.
- The NPV value of the fixed PV system reached 120,334 USD which is undesirable compared to the single axis and dual axis which the NPV value is 22,860 USD and 22,354 USD, respectively. Since the NPV for 1 and 2 axis tracking systems is lower, the payback period is extended when compared to the fixed panel.
- The calculated PBP for three systems is nine years for the fixed system and fifteen years for single and dual-axis systems.
- This study also shows that achieving a sustainable energy transition is feasible while lowering carbon emissions by optimizing largescale PV installations in Zakho city for the system load curve.
- Indeed, according to the data, the dual-axis system was feasible and preferable to the other two systems.
- Currently, the authors are working on this study experimentally to expand this work more acceptable and efficient for practical applications.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the author.

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